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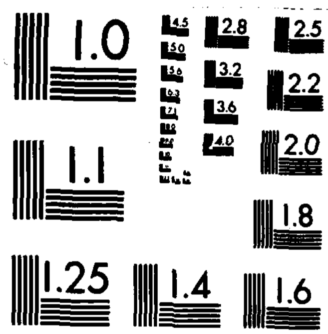

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Optical output stabilization method for direct current arc lamps

by

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A simple, effective technique for stabilizing the optical output of direct current (dc) arc lamps is described. The large output fluctuation due to arc wander in a commercially available lamp and power supply is minimized by the introduction of an alternating current (ac) waveform superimposed on the dc source voltage in conjunction with detector averaging. Arc stability is monitored indirectly by the detection of arc excited fluorescence from a standard sample. The monitored lamp output is typically maintained to within 1% relative standard deviation (RSD) by this method. Data are presented supporting the

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OPTICAL OUTPUT STABILIZATION METHOD

FOR

DIRECT CURRENT ARC LAMPS

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Abstract

A simple, effective technique for stabilizing the optical output of direct current (DC) arc lamps is described. The large output fluctuation due to arc wander in a commercially available lamp and power supply is minimized by the introduction of an alternating current (AC) waveform superimposed on the DC source voltage in conjunction with detector averaging. Arc stability is monitored indirectly by the detection of arc excited fluorescence from a standard sample. The monitored lamp output is typically maintained to within 1% relative standard deviation (RSD) by this method. Data are presented supporting the theory that arc wander is significantly reduced by the addition of an AC component to the DC lamp power. Various methods of AC introduction are discussed along with the design of a controllable oscillator circuit. The effects of variations in AC voltage and frequency on optical output stability are examined.

Introduction

Direct current (DC), high pressure arc lamps are routinely used in research areas which require high intensity, broadband illumination sources. Research in optical spectroscopy[1,2] and solar energy[3] are two areas which rely heavily on the use of DC arc lamps. The popularity of these lamps is most often due to their similarity to natural sunlight in spectral distribution and intensity. Unfortunately, the use of arc lamps for spectral measurements is severely limited by power instability and arc wander. Numerous publications[4-6] over the last two decades have addressed the problem of lamp current regulation. These improvements in DC power supplies have proven adequate in regulating lamp power. However, arc wander is not exclusively dependent on input power stability.[3-4] One study[7] indicates that the constant heat flux directed toward the anode in DC arc lamps produces abnormalities on the electrode surface which cause arc wander.

One very popular method of reducing the effects of arc wander uses an optical feedback circuit.[4] These devices generally use a beam splitter to divert a portion (usually 10%) of the light output to a photodiode which converts it into an electrical signal. This signal is used to adjust the lamp current supplied via a negative feedback amplifier circuit. The optical feedback device is not intended to reduce arc wander but rather attempts to stablize the output intensity. In fact, the probability of arc wander is likely to increase as the input power changes to compensate for arc movement. Therefore, the stability gained by such a device is limited to cases in which the optical output is dispersed over a relatively large area so that arc wander does not seriously attenuate the detected output. This is necessary for the small change in current to stabilize adequately the optical output.

Another method of reducing arc wander has been suggested[8] which uses a magnetic field to limit arc movement. The magnetic field is applied perpendicular to the arc with its strength and position determined experimentally. This method would be difficult to standardize reliably for most research applications but it does indicate the potential for controlling arc movement with an electromagnetic field. If the external magnetic field is rotated around the arc, it causes the arc to bend with the field. In our estimation, the rotating magnetic field also induces an alternating current (AC) in the lamp which may contribute to optical output stabilization.

This paper presents the use of an AC waveform superimposed on a DC arc lamp for stabilization of the optical output. The arc stability is monitored indirectly by fluorescence detected from a standard sample. The effects of AC voltage and frequency on lamp stability are investigated. Several methods of AC introduction are also proposed along with the design of a voltage controllable oscillator circuit.

I. Principle of Operation

The stabilization technique described is based on the addition of a systematic time dependent voltage (square wave, sine wave, etc.) to the DC input power of a DC arc lamp. As previously discussed, it is necessary but not sufficient that the DC power be well regulated for a stable arc. Therefore, the AC voltage must be added to a well regulated DC voltage to maintain maximum stability. Arc stability which we will define as an arc with a predictable output and little random character, is produced by the AC modulation. One possible explanation for this stabilization is based on the distribution of heat within the interelectrode region. It has been suggested that a more even heat flux in the arc region may reduce the formation of electrode surface abnormalities and thereby improve arc stability.[9]

The addition of a systematic function such as a sine wave to the lamp power does, however, create a problem. This method actually produces an arc which is synthetically noisy. However, if the detection time window exactly matches one wavelength period, then this noise will cancel. This, of course, is also true for any integer multiple of the AC wave period.

II. Experimental

The 150-watt DC, xenon arc lamps used in this study were obtained from Canrad-Hanovia, Newark, NJ. The power supply used was a 250-watt universal power supply form Ealing Corporation, South Natick, MA. The power supply specifications quote stability to within 0.1%. In these studies, arc stability is monitored by detecting the relative fluorescence from a standard sample which is excited by the arc lamp. Initial studies used chlorophyll a in acetone as the standard but due to photodecomposition of this sample, a standard rhodamine B sample fixed in a solid matrix of polymethylmethacrylate was obtained from Perkin-Elmer Corporation, Oak Brook, IL. Fluorescence is collected at a right angle to the excitation beam and dispersed into its component wavelengths by an Instruments SA, Inc. UFS-200 spectrograph. The dispersed image is then detected by a 512 element intensified linear photodiode array obtained from Tracor Northern, Middleton, WI. This provides an accurate measure of arc wander since at low absorbance (<0.01) relative fluorescence intensity, I_f is directly proportional to the excitation intensity, I_0 by equation (2), where Φ_f is the quantum efficiency of fluorescence and A is the molar absorbance.

$$I_f = \Phi_f I_0 A \qquad (1)$$

Thus, the maximum fluorescence signal is obtained when the arc image is exactly focused via the excitation optics onto the sample cuvet, whereas a decrease in signal indicates either arc wander or a change in the total optical output.

Since the monitored DC power is stable and physical observation of the arc image indicates arc wander, any change in the detected fluorescence signal can be attributed to arc movement. A typical experiment entails the collection of successive relative fluorescence measurements from which the mean and relative standard deviation (RSD) are calculated.

Several possible methods for superimposition of the AC waveform on the DC source may be considered. Fig. 1 provides examples of those that are imme diately obvious to us. The simplest and most efficient method of AC introduction is shown in Fig. 1 (a). In this method, the AC signal is introduced directly to the adjustment pin of the voltage regulator. A circuit which uses a voltage controllable oscillator (LS628) is shown in Fig. 2. This circuit is used in this study since it allows the selection of a wide range of oscillation frequencies (Hz to MHz) for stability optimization of different lamps. The output of the LS628 is a TTL square wave which is superimposed on the DC source voltage via the 5 amp controllable power regulator, LM338. It should be intuitively obvious that the discussion of systematic fluctuations provided by sine waves is also applicable to square waves. Up to 3 amps are supplied to the lamp from the LM338 with the balance of the current being supplied by a network of resistors within the Ealing power supply. The total current is monitored and stabilized by regulating the current supplied by the LM338. The AC voltage is usually held to approximately 5% of the DC voltage. However, this may vary with different lamps, power supplies, and operating frequencies. The circuit in Fig. 2 was incorporated into the Ealing power supply for easy implementation of this technique.

III. Performance

The results of 8 consecutive experiments designed to evaluate the applicability of our proposed technique are presented in Table I. These experiments were conducted over 10 minute time periods both with and without AC stabiltzation. It is interesting to note that without our AC stabilization the RSD is often held close to 1% but the average range in the RSD of successive experiments is indicative of an unstable arc. As long as the power supplied to the arc is well regulated, the arc may remain stable for relatively short periods of time. However, the arc wander noise component will eventually show up as large fluctuations in detected arc intensity. It is especially critical to eliminate such fluctuations in fluorescence measurements where data are often acquired somewhat randomly. These fluctuations have been significantly reduced, if not totally eliminated, by our AC stabilization method as indicated by the small range in RSD measurements recorded in Table I. There is also a general improvement in optical output stability over the previous case which used the commercial power supply without the AC method. A typical trace of relative fluorescence intensity detected over a 10 minute period with and without our AC stabilization is given in Fig. 3. The calculated RSDs for these two experiments are 1.19% and 6.98% respectively. An AC frequency of 50 Hz and 2 V was used for the stabilized data presented in Fig. 3(a). Figure 4 reports a similar experiment conducted over a one hour period with an RSD of 1.00% for the AC stabilized case and 5.58% for the unstablized. The AC stabilization used in this case was 3 KHz and 6 V. Thus, long-term, as well as, short-term stabilization can be maintained using this AC technique.

To assess the physical effects on the arc and its optical output by the AC component, we compared the lamp output with the AC signal superimposed on the lamp. A sine wave of about 200 Hz and 3 V was placed on the DC power. The optical output was attenuated and transmitted by a fiber-optic to a photomultiplier tube (PMT). A dual trace oscilloscope was used to compare the input signal to the signal detected by the PMT. A square wave was used in place of the sine wave in a similar experiment. Both experiments exhibited excellent correlation between the input power to the arc and its optical output. This indicates that the introduction of an AC signal to the arc actually modulates the optical output intensity.

Having established the effectiveness of the AC stabilization method, the next experiments were designed to evaluate the various parameters which affect the stablization. Three parameters were investigated in an attempt to determine the conditions required for optimum stabilization. The three parameters evaluated were 1) width of detection window 2) AC frequency and 3) the AC voltage imposed on the lamp. Since we postulate that there is both a physical arc stabilization and an optical averaging effect responsible for detected optical stability, all three of these parameters are evaluated independently and collectively.

Optical averaging is necessary since the output is modulated by the AC component. Detected stability generally improves as the integration time approaches and exceeds the length of one AC wave period. Phase differences between optical output and detector modulation can cause a small decrease in observed stability at short integration times that are not exactly matched to the optical output modulation frequency. Therefore, it is important statistically to average over several AC wave periods. We have found that averaging over 10 or more wave periods provides suitable stability.

The effect of AC frequency on arc stability separate from the optical averaging effect is given in Fig. 5. For this study, a detection window was selected long enough to observe at least 10 wave periods of the lowest frequency AC component studied. This ensured that an averaging effect was present for each frequency so that the relative stability could be measured independent of optical averaging. These data prove that there is indeed arc stabilization due to the AC component aside from the optical averaging. Figure 5(a) gives the frequency response for a new lamp. At this point, it is interesting to compare the frequency response of a new lamp with that of an old lamp which had been previously discarded due to excessive instability. Figure 5(b) presents this data for an old lamp. It is immediately obvious when comparing the two frequency response curves that, the overall stability of the new lamp is, as expected, superior to that of the old lamp. However, at certain frequencies the old lamp is more stable than the new one. Therefore, this data indicates the possiblity for increasing lamp longevity by the described method.

The last of the three parameters to be discussed is the AC voltage imposed on the lamp. In order to provide a wide range of controllable voltages for this study, a 10 amp controllable power regulator, LM396, and variable frequency generator was used. These replaced the 5 amp power regulator, LM338, and the voltage controllable oscillator circuit of Fig. 2 because the previous circuit was unable to supply the necessary power needed to produce over 4 VAC. Figures 6(a) and 6(b) give the results of stability versus AC voltage measured at the AC frequencies of 100 Hz and 3.3 KHz, respectively. These data indicate that the AC frequency and voltage are not strictly independent of one another. There exists an upper voltage limit for a given frequency which when exceeded will extinquish the arc. This is why Fig. 6(a) and 6(b) do not cover the same voltage range. Generally, the higher frequencies allow higher modulation voltages. However, it is important to note that, the frequency and voltage will combine at some point to effect optimum stability. This usually occurs over a range of voltages for a given frequency but the width of this voltage region diminishes as the frequency increases.

IV. Discussion

The AC waveform method of DC arc lamp stabilization is very effective, yet simple and versatile to implement. It has been shown experimentally that this is due to the time dependent voltage in conjunction with optical averaging.

he data presented fully supports a statistical explanation of optical output tabilization for DC arc lamps.

All of the various parameters discussed (detection time, AC frequency, AC 'oltage) combine to make this a very versatile technique. Optimum stability is ıchieved with a detection window 5 to 10 times longer than one period of the AC ıignal. However, there are numerous trade-offs among the parameters discussed which make this technique applicable to a wide range of experimental situa- :ions. For example, experiments which must be conducted at high lamp fre- ıuencies can be accomodated just as easily as those conducted at low fre- ıuencies by simply adjusting the AC voltage and the detection time. The only limitation would be in using those frequencies which cause acoustic resonance ınd arc instability.[9] However, the acoustic resonance frequencies for most lamps are of much higher frequencies (>10 KHz) than those which would be com- nonly used. It should also be possible to use a frequency on either side of the resonance frequency without affecting the arc stability.

This method should be especially useful in optical spectrophotometers which use arc lamp sources. Fluorimeters and single-beam absorption specto- neters are especially vulnerable to unstable optical sources since they gen- erally acquire measurements randomly. Therefore, they are unable to compensate for random fluctuations in source intensity. The other stabilization techni- ques such as improved power supplies and optical feedback devices used with these instruments are often ineffective and cumbersome. The simplicity and demonstrated effectiveness of our AC stabilization method make it a very at- tractive alternative for such cases and should result in more reliable photo- metric measurements.

Further investigations will be conducted to determine the physical effects AC on the electrode surfaces and on how the AC affects the longevity of the np. It is possible that the AC actually reduces electrode pitting by the en distribution of heat which could also increase the useable lifetime of DC : lamps. The long-term stability of these lamps could possibly be improved ill further by combining optical feedback with the AC stabilization method.

Acknowledgments

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Figure Captions

Figure 1. Examples of AC waveform introduction.

Figure 2. Variable frequency oscillator circuit.

Figure 3. Typical trace of relative fluorescence intensity over a ten minute time period; (a) with AC stabilization; 50 Hz, 2 V, (b) with conventional stabilization.

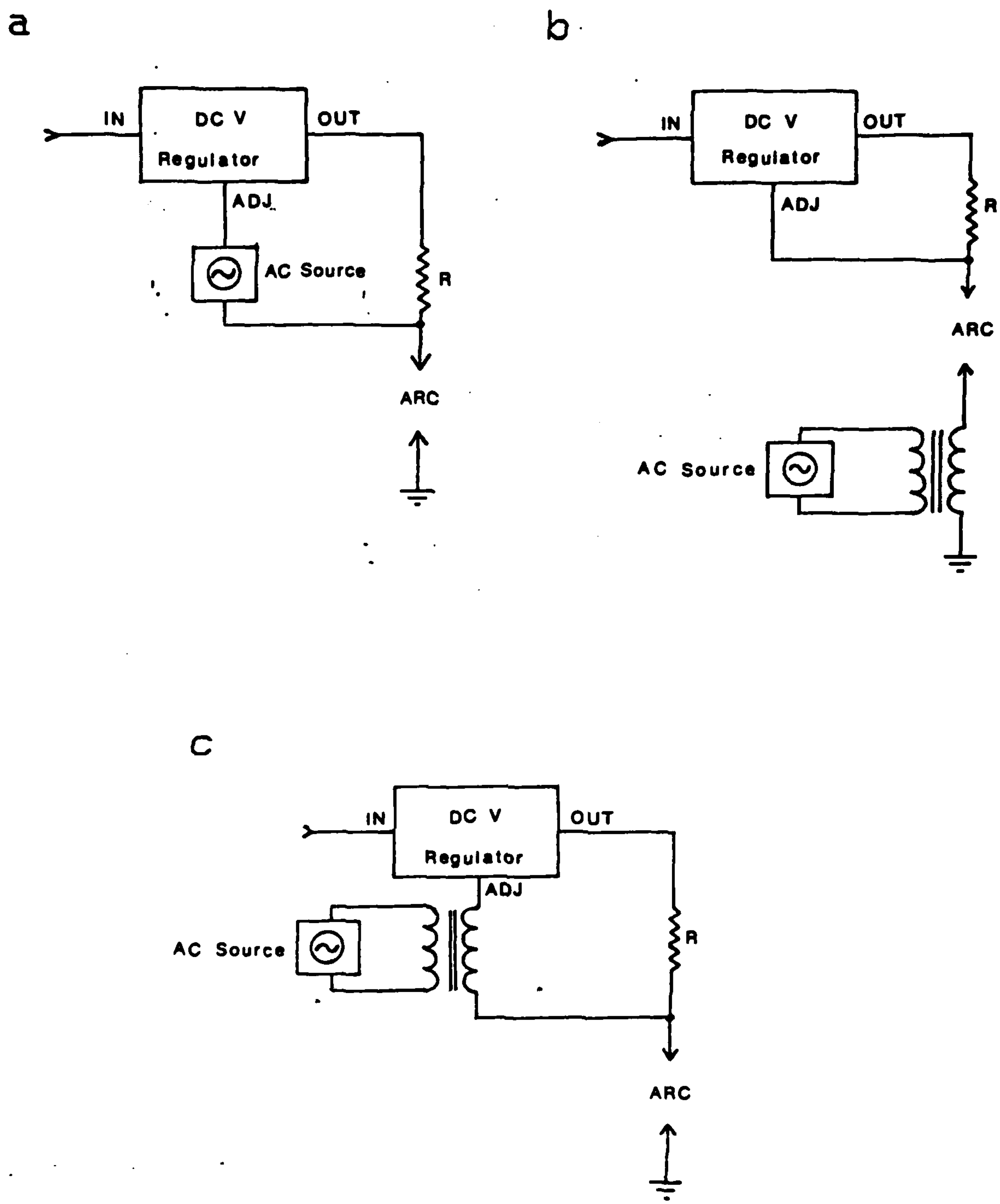
Figure 4. Typical trace of relative fluorescence intensity over a one hour time period; (a) with AC stabilization; 3 KHz, 6 V, (b) with conventional stabilization.

Figure 5. Effect of AC frequency on arc stability; (a) new lamp, (b) old lamp.

Figure 6. Effect of AC voltage on arc stability (a) 100 Hz, (b) 3.3 KHz.

Table I. Relative standard deviation for eight consecutive experiments both with and without AC stabilization.

Time	W/O AC	AC
10	1.07	0.69
20	1.32	0.92
30	3.80	0.79
40	18.00	0.68
50	0.93	1.26
60	0.91	0.77
70	1.49	1.04
80	14.41	1.10
Mean =	5.11	0.91
	17.09	0.57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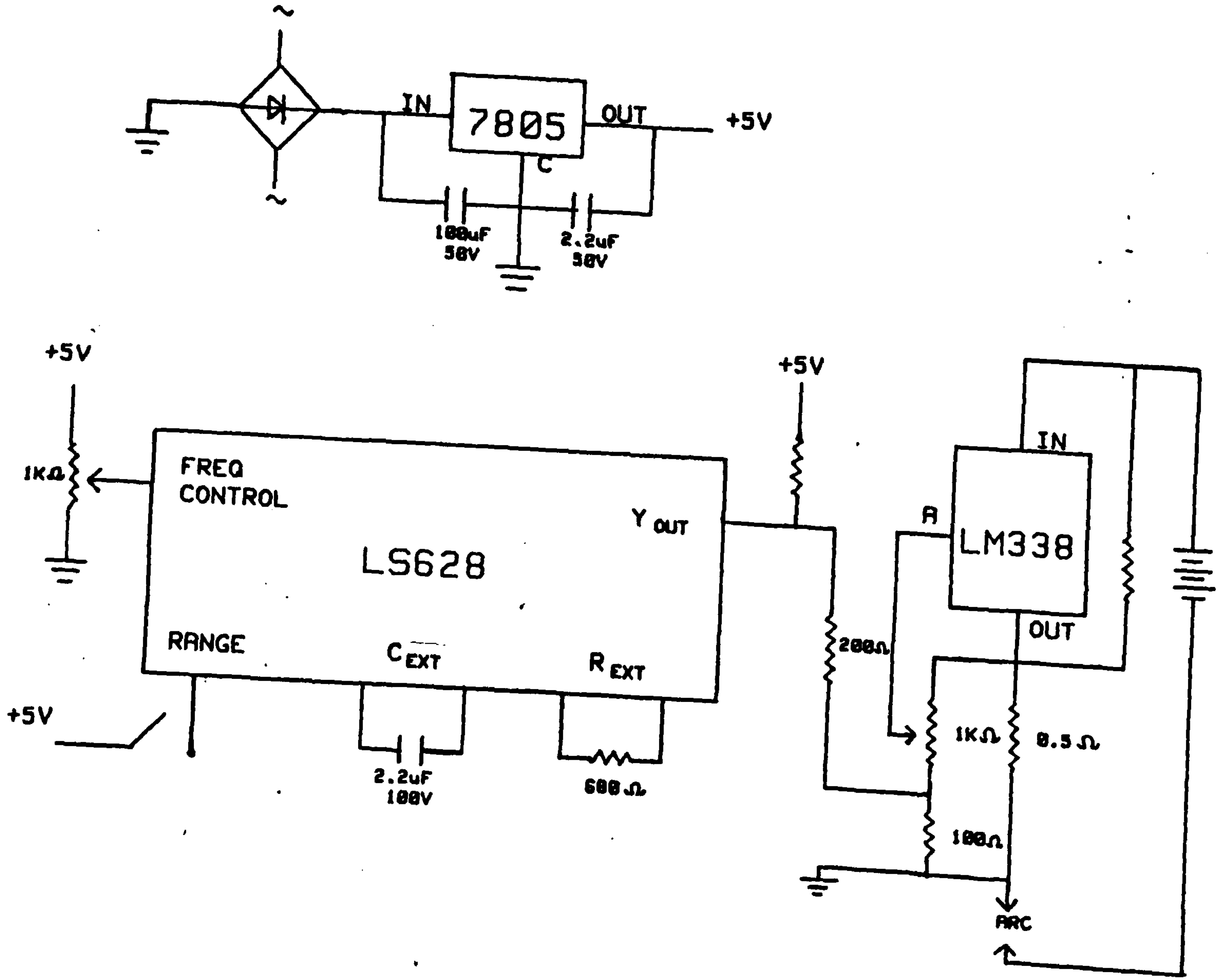
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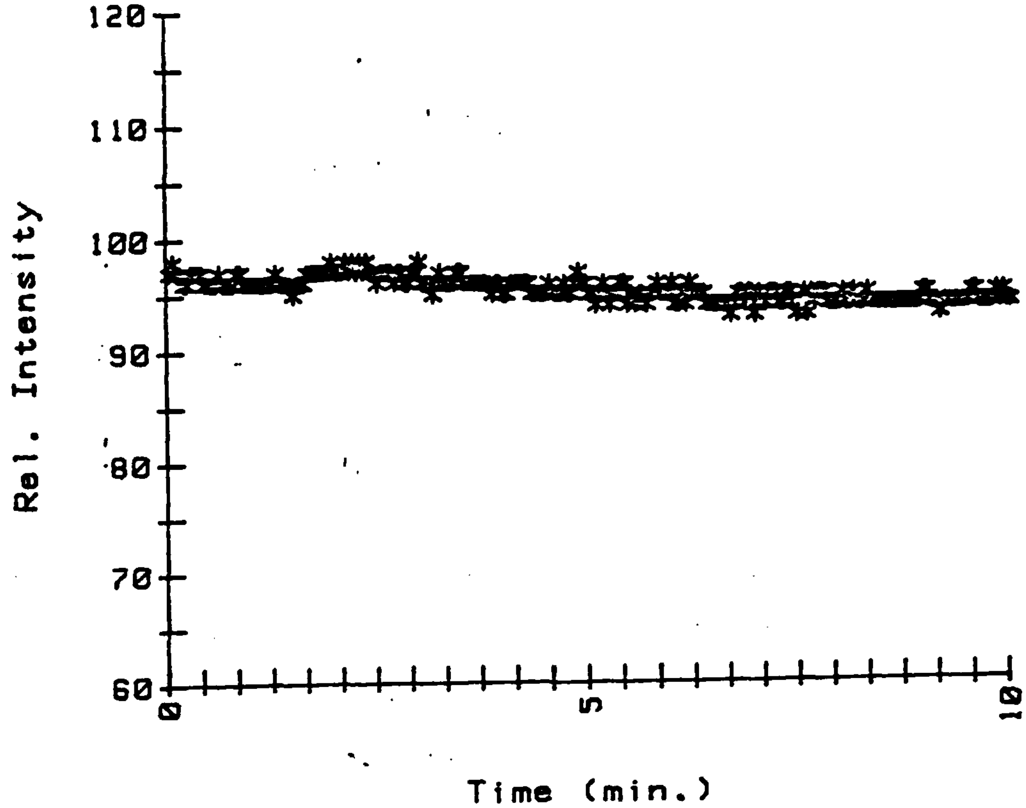
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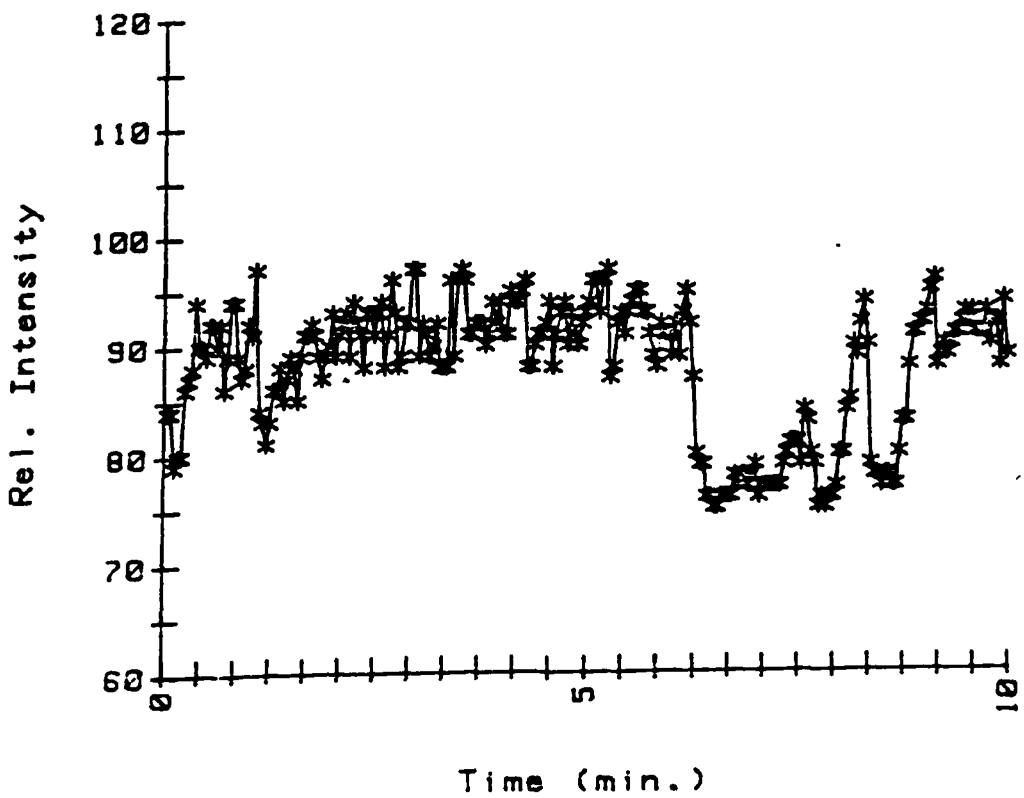
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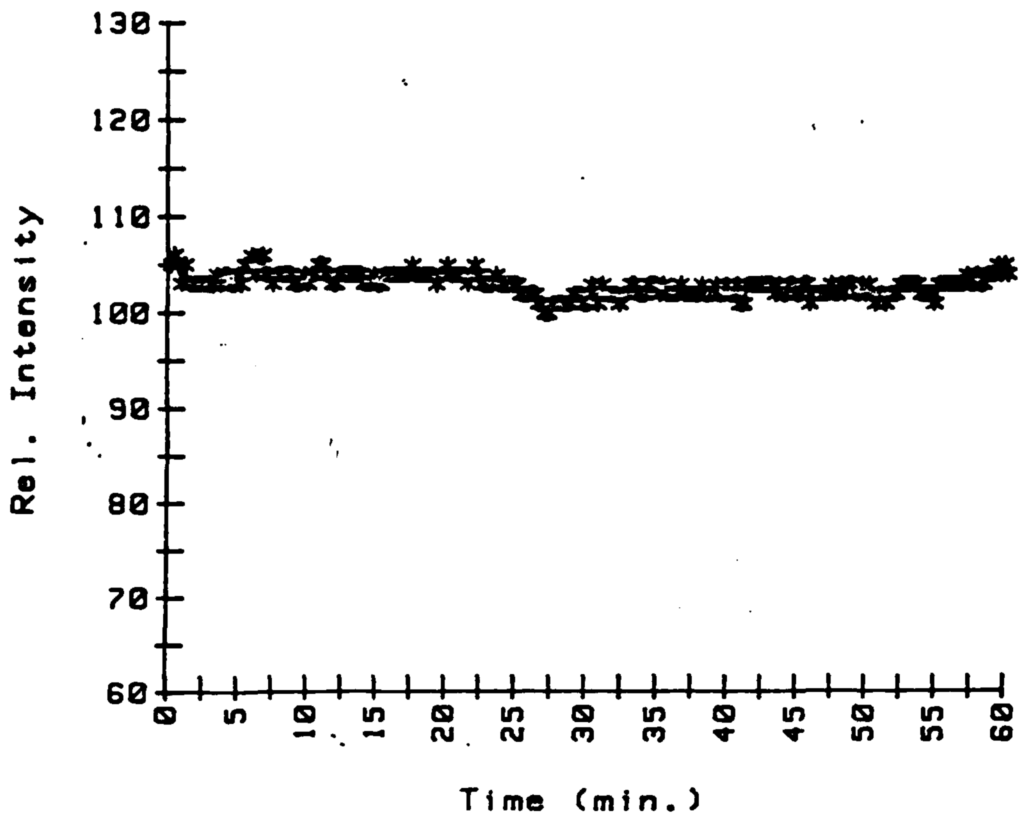

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Time (min.)

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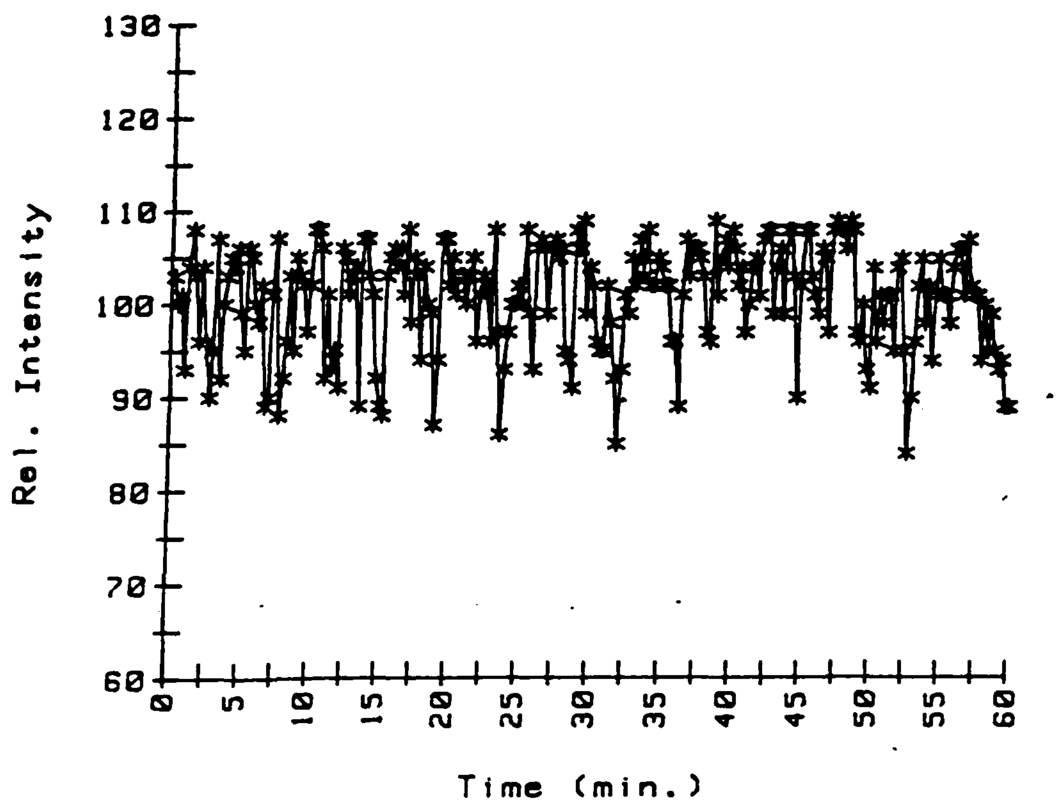

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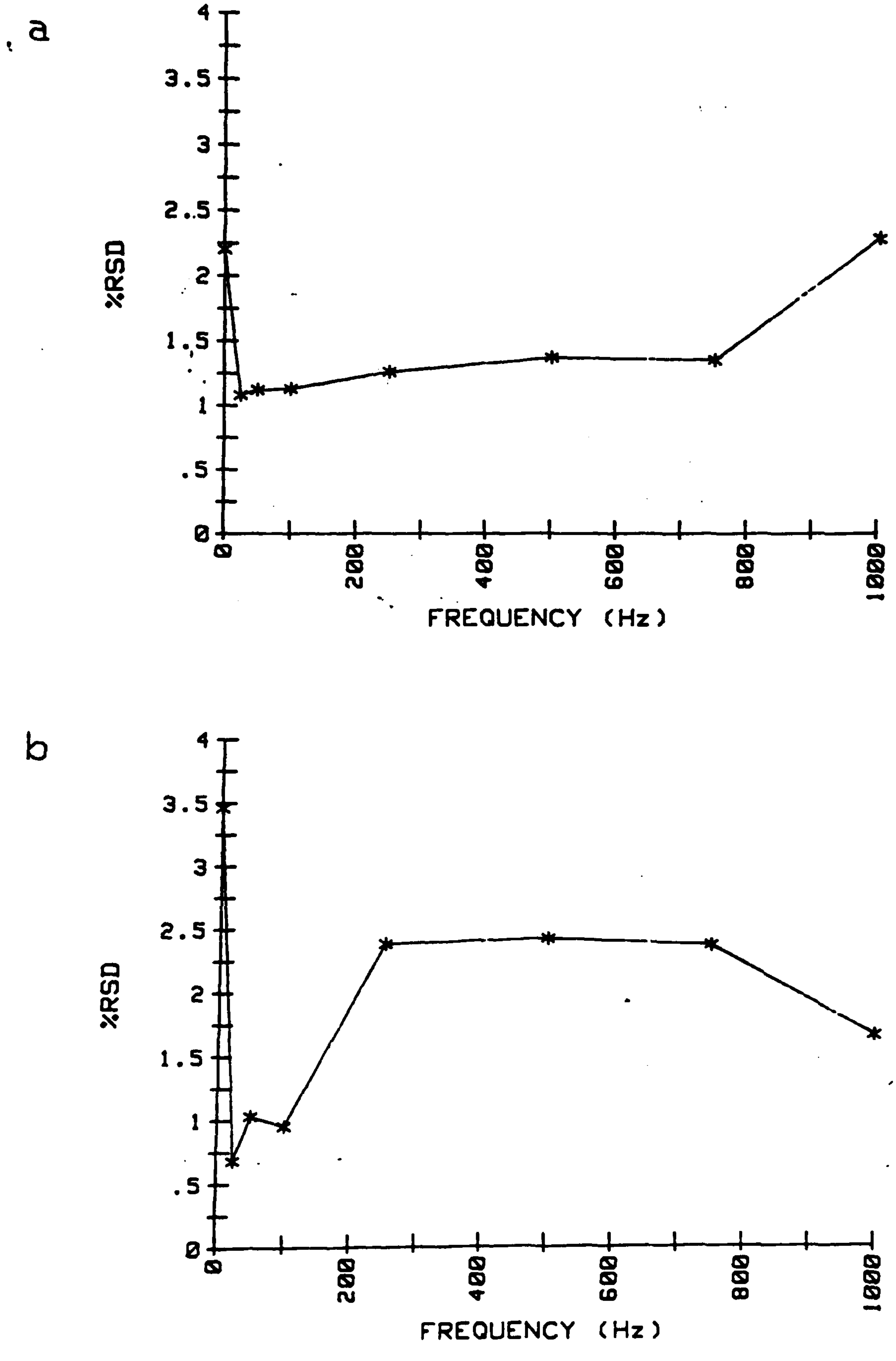
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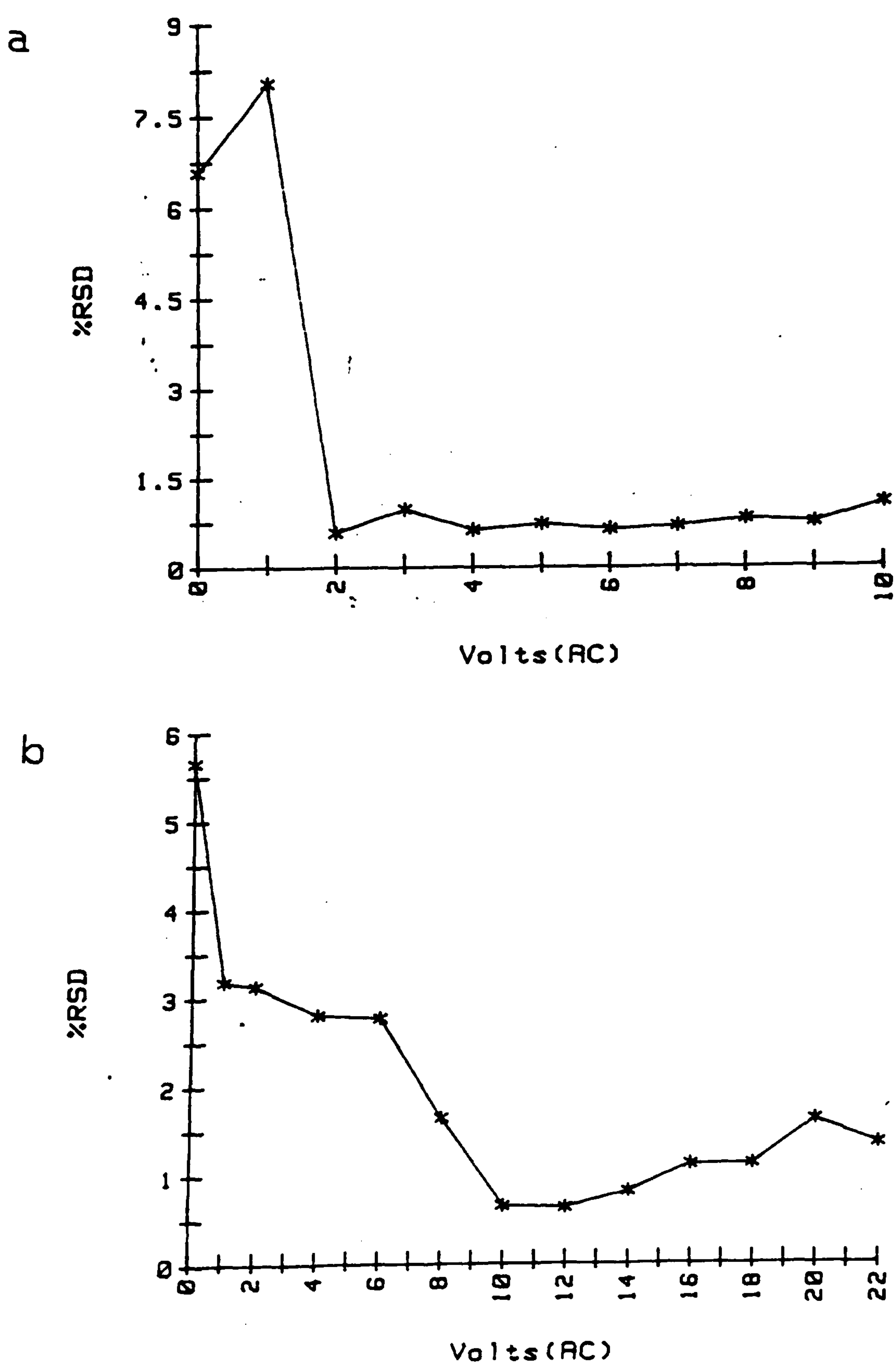
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